AN ANALYSIS OF INSECT GROWTH CURVES*

By Laurence C. Woodruff
University of Kansas, Lawrence, Kansas

The purpose of this paper is not to contribute new material on statistical analysis but rather to point out the many valuable and helpful features of the ratio or logarithmic chart as a means of depicting growth in insects. This device either is unknown to the majority of entomologists or is not well enough understood to be accepted and used by those who have occasion to discuss growth curves. Since, as I will attempt to show, the ratio chart gives the only true and accurate conception of growth, it is most unfortunate that this type of illustration has not been more fully appreciated.

Unorganized masses of figures tell us little or nothing. The same facts tabulated in an orderly manner may reveal pertinent information, if we have the patience to analyze columns of figures. But when these data are arranged in the form of a chart or graph which can be deciphered almost at a glance, the evidence is quickly conveyed to the reader. Burdensome details are relegated to the background and the salient features are shown vividly through the use of points, lines, or surfaces. The principal use of graphs in biological work is to present large groups or series of figures in such a way that they will be intelligible in their entirety and so arranged as to give the clearest conception with no possible mistake as to their explicit meaning. Graphic devices often serve to popularize the results of an investigation and to force the information to the attention of the casual reader who otherwise might not take the necessary time to read the entire article.

During the past few years there has been a great increase in the appreciation and application of statistical charts in entomological literature and as a consequence we are faced with the problem of stabilizing our methods in order to avoid misinterpretation of the information presented and to make such information

*Contribution from the Department of Entomology, University of Kansas.

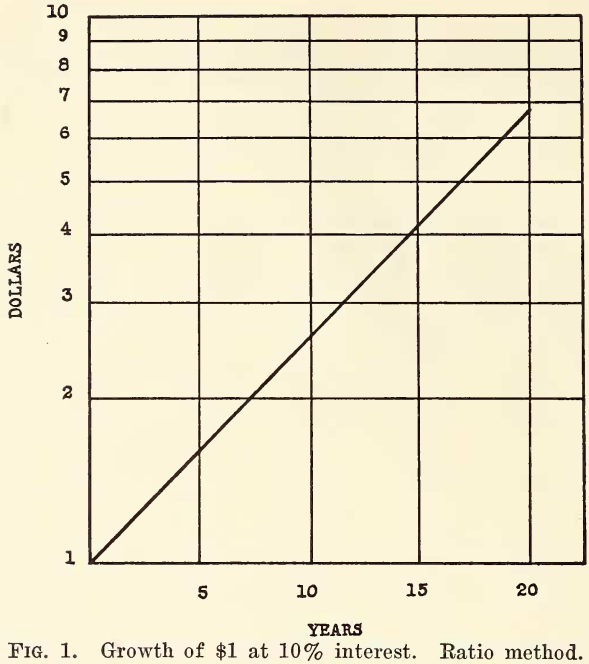

FIG. 1. Growth of $1 at 10% interest. Ratio method.

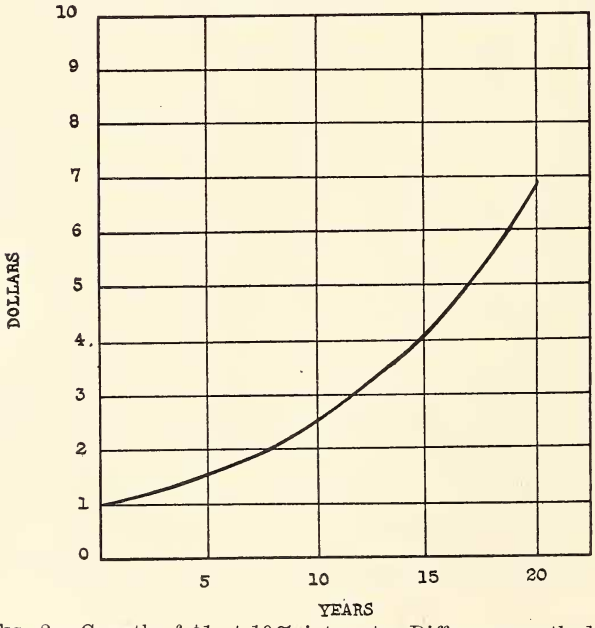

FIG. 2. Growth of $1 at 10% interest. Difference method.

comparable with that of contemporary colleagues. The old question of the responsibility of a writer in analyzing his data comes to the foreground repeatedly. Surely, no one is better fitted to give a correct commentary than the investigator who has planned and executed the problem. But many times the facts speak for themselves in no uncertain terms when correctly portrayed in the form of a graph and no review is necessary. Care and thought in planning graphs are especially important since many readers have neither the critical ability nor the background necessary to protect themselves from misinterpretation. A statistical method or formula may become a dangerous weapon when applied to prove a pet thesis. Even without a deliberate intention an author often gives the wrong impression or distorts the true relation between cause and effect through the use of a faulty diagram. Great caution should be exercised in the selection of the type of chart to be employed, basing the choice upon a knowledge of the principles involved and at the same time keeping in mind the specific features of the problem at hand.

What, then, shall be the purpose of a growth curve for insects and how shall we go about picturing it in the most accurate and unmistakable manner? It depends entirely upon the emphasis; whether it shall be one of ratio or of amount of variation. Most of such information in entomological literature, or as a matter of fact in that of all biology, has been shown by simple line curves involving the charting of equal spaces for equal quantities and where weights, lengths, or other measurable units are plotted against time. This is known as the difference or absolute magnitude chart. In so far as a study or comparison of actual numerical data is concerned such a graph serves admirably, but it fails in the one purpose for which it is being used—that of showing the growth rate. For in the analysis of insect growth, while we are interested in the absolute magnitude, the relation or ratio of that magnitude either to itself or to other magnitudes is the all-important consideration. In short, we are concerned more with the proportionate than with the actual increase. We need then a diagram not of quantities as in the difference charts, but of ratios where isometric vertical distances do not represent equal absolute increments but equal proportional increments, that is,

equal rates of increase. Nothing meets these requirements quite so well as does the ratio chart.

The principle governing the ratio chart is the presentation of numerical data in relative magnitudes, not in absolute magnitudes. The avowed purpose then is that of exhibiting and comparing ratios. This type of chart is laid out upon coordinate paper so that the vertical lines represent absolute values while the horizontal lines represent logarithmic variances, where equal spaces mean equal magnitudes of change since the diffrence between the logarithms of two numbers is the ratio between these two numbers. This effect may be achieved in two ways: first, by converting the observed values into logarithms which may then be plotted upon equidistant spaces on the graph or, second, by employing especially prepared paper (see Fig. 3) on which the logarithmic ordinates are laid off on the vertical axis, using the logarithms of 1 to 10, and are numbered with the appropriate power of 10. This type of paper is very convenient in plotting growth curves and may be purchased from several supply houses in the simple form or in two and three cycles. Many persons shy at the mention of logarithms but they need have no apprehension since this "semi-logarithmic" graph paper can be used safely with no knowledge of logarithms in as much as the rulings are labelled with absolute values and curves may be plotted directly. The rapid decrease in the absolute differences between the logarithmic rulings at once engages attention but when this principle is applied in constructing the ordinate scale, equal vertical spaces anywhere on the diagram represent equal ratios of difference. Note in Figure 3 that the distance from level one to level two is the same as from two to four or from four to eight, all three being equal proportionate increases. Thus uniformity in the percentile rate of growth or increase is pictured on the ratio chart as a straight line. If the curve bends upward the rate is increasing and if it bends downward the rate is decreasing. Comparative gradients of separate parts of the same curve or of different curves indicate equal rates of increase or decrease, since a given per cent of increase is always represented by the same vertical distance upon the diagram regardless of the absolute magnitude.

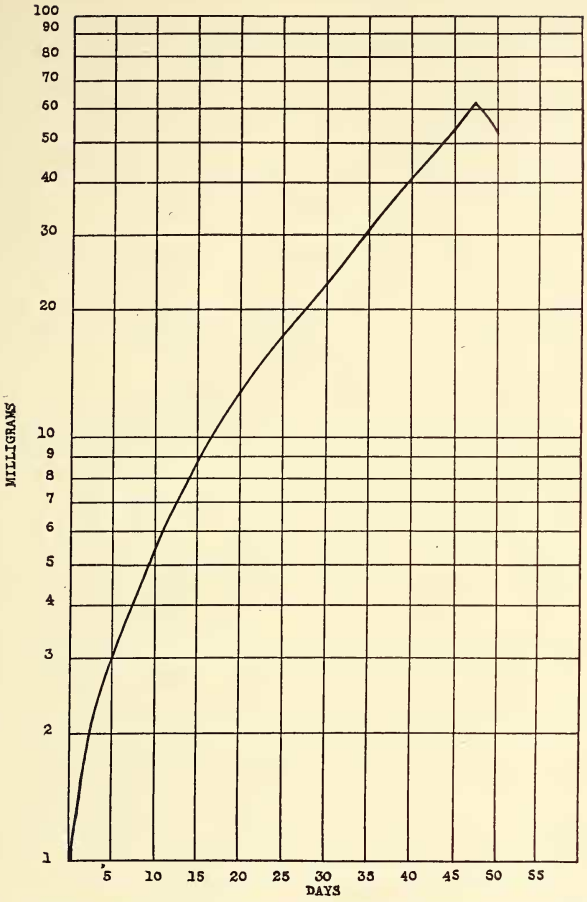

Fig. 3. Growth curve for *Blattella germanica* (somewhat idealized). Ratio method.

As has been mentioned frequently in this article, the principal argument for the use of the ratio type of chart in picturing growth curves of insects rather than one based on absolute values is the fact that the controlling interest is in the rate of increase or decrease which is not shown on the difference chart. Why then should an author employ a device which fails in the very purpose for which it was chosen? The slope of the curve in the difference chart has no meaning other than that of indicating the

trend in the change of absolute magnitude while to a reader accustomed to interpreting ratio diagrams "the slope of the line tells the story," and that story can be read at a glance. Furthermore, while the ratio chart primarly expresses rates of increase or decrease, the absolute values may be read directly from the chart, thus making this type of diagram available for both purposes. The best that can be said of the difference chart is that it shows any change in value and usually indicates the grosser rate but, uniformity is represented by an exponential curve which cannot be read accurately at sight and must be interpreted from its relation to the base. Such mental operations are difficult and often the results are misleading or confusing.

The advantages of the ratio chart over the difference chart are many. In the comparison of two curves plotted upon ratio charts, it is the slopes that are comparable and not the points above the base line. Hence, we may move either curve bodily, until the two approximate each other, merely by reducing all numbers by a common divisor. The distance above the base line has no significance as it has in the difference chart and thus growth curves for animals with widely different masses may be safely and accurately compared on the same diagram, an operation rarely possible by other methods. Sometimes, factors and relationships in the problem of insect growth which have escaped observation by the investigator are revealed through the use of ratio charts. One great expediency is in forecasting. Where the changes in rate of growth are evident from the slope of the curve, future developments may be anticipated by extrapolation with a better than fair degree of accuracy.

The ratio chart is not without inconveniences. One common criticism is that it cannot be read easily. But this applies only to the beginner, who because of being accustomed to other types of charts may have some difficulty in orienting himself to the direct course of the ratio curve. When the logarithmic rulings are marked with their absolute values, the graduated ordinates soon become as familiar as in any other type of chart. Another and somewhat more serious disadvantage is the fact that there is no base line, which means that it is impossible to plot values below the lowest power of 10 selected or to compare positive and

negative quantities. As a general rule, however, this is not necessary in charting growth curves for insects.

The classical example of the fallacious impression which may be obtained of growth curves shown by the difference method is

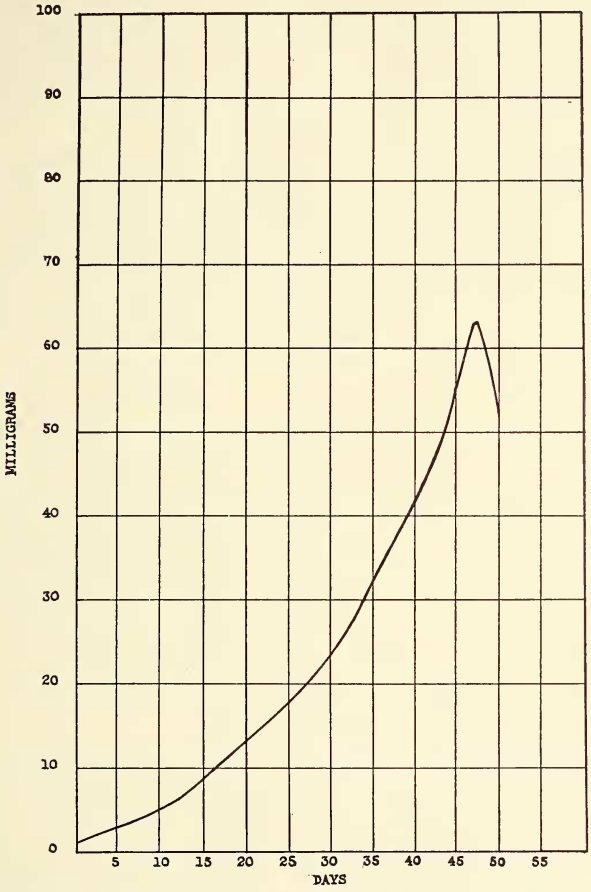

Fig. 4. Growth curve for *Blattella germanica* (somewhat idealized). Difference method.

the plotting of interest rates. In Figures 1 and 2 the growth of \$1.00 at 10%, compounded annually, has been charted by the two methods so that they may be contrasted. Common sense tells one that the ratio is constant throughout the entire period and

this is shown most forcibly in Figure 1 where the growth is represented by a straight line, indicating uniformity in the rate. Figure 2 shows identically the same data but with the curve plotted by the arithmetic difference method. Here we are plotting differences in the annual accumulations but the average reader would naturally enough be misled to infer falsely that the rate increases progressively, since this is indicated by the slope of the line. In this chart the growth is represented by an exponential curve and the uniform rate is lost to the eye.

In entomological literature one finds that this same mistake has been made repeatedly in connection with the growth rate of insects. In Figures 3 and 4 I have plotted the growth of a roach (*Blattella germanica*) as a working example. Note that in Figure 3 where the actual progress is shown by the ratio method, the rate in increase is most rapid during early life and that this diminishes slightly with time, the decline of the curve to the right indicating a decreasing rate. The type of curve plotting used in Figure 4 is actually not intended to show the rate of growth but has been so interpreted by many authors who because of such an assumption are led to speak of the growth as slow during the initial period but gradually increasing and becoming most rapid during the later periods of the insect's development. It is the levels of points on this type of curve which are significant and not the slope. Yet the characteristic of a curve which usually attracts the interest of the observer is its comparative direction and the points are examined only when a deep interest in the problem stimulates detailed study.

Since this situation prevails in the present use of the difference chart for showing growth curves of insects and since such charts for distinct insects are not truly comparable, it seems that for the sake of accuracy it is high time that the ratio chart finds its place in entomological research. One thing is certain—that greater uniformity in methods of presenting growth curves by the various workers is essential in order to render similar data comparable either at the same time or at successive periods.

SUMMARY

Difference charts in which the absolute values are used in plotting growth curves of insects are unsatisfactory since the line

of the curve has no significance when interpretations of rate are desired, showing only the changes in magnitude. On the other hand, the ratio chart, whose basic concept is that of relative rather than absolute change, indicates the true rate of growth through the comparative changes in the curvature of the line. The features of a curve which attract the greatest attention are concerned with direction or slope. These features, therefore, should not be misleading as they are in the difference chart but a true representation of the course of growth. In the ratio chart, increases or decreases are shown proportionately by a curve which denotes the trend of the growth rate accurately and clearly, uniformity being designated by a straight line. Arithmetic values may be assigned to the logarithmic ordinates so that changes in absolute magnitude can be easily interpreted and thus a dual purpose chart is obtained.